Surface Modification of Aluminum by Electrical Discharge Coating with Tungsten and Copper Mixed Powder Green Compact Electrodes

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Abstract

EDM is a prominent non-traditional machining process, which is widely used for machining hard materials which is not possible byconventional processes. A very special aspect of this process is a surface modificationby material transfer from the tool electrode to the work-piece which is commonly known as electro discharge coating (EDC). In this work, electrode prepared with tungsten (W) and copper (Cu) powder by powder metallurgy (PM) route used as tool material and pure aluminum is used as work-piece. Using reverse polarity (tool as anode and work-piece as cathode) in electro discharge machine a hard composite layer of WC-Cu has been deposited on the Aluminum work-piece surface. The effect of compaction pressure during tool preparation by PM method and peak current (Ip) and pulse on time (Ton) during EDC process on Deposition Rate (DR) and Tool Wear Rate (TWR) have been studied. A Taguchi L18 experimental design method has been used to study the effect of various process parameters on EDC process.

Keywords: Electro Discharge Coating (EDC), Powder metallurgy (PM) electrode, Deposition Rate (DR), Taguchi analysis.

1 Introduction

Electro Discharge Coating is an aspect of coating technique by material transfer from tool electrode to work piece using EDM. It is a non-conventional coating technique in which hard layers are obtained by deposition of carbide of Ti, W, Cr etc. It can be done either by Powder metallurgy (PM) tool-electrodes or Powder Mixed Dielectric method. Gangadhar et.al (1991) as part of surface modification of steel, used bronze compacts having 90% copper (Cu) and 10% tin (Sn) as tool for EDC and obtained a layer of Cu and Sn on steel. A trace amount of carbon layer has also been deposited which came out from hydro carbon dielectric. Lee et.al (2003)used WC compact electrodes prepared under compaction pressure of 100 to 540 MPa and sintering temperature of 1000°C for EDC process and found that the use of partially sintered powder metallurgy (PM) electrode can encourage surface modification because the binding energy between grains is reduced as compared to fully dense products. Patowari et.al (2010)has been used artificial neural network model in surface modification by EDM using tungsten and copper powder metallurgy sintered electrodes. Material transfer rate and average layer thickness were correlated with sintering temperatures for EDC process. Wang et.al (2002) studied surface modification by using EDM with the help of Ti and other PM compacted electrodes on carbon steel. Samuel and Philip (1996) compared electrodes in EDM with cutting tools in conventional machining.P/M electrodes are found to be more sensitive to pulse current and pulse duration than conventional solid electrodes. An L18 fractional factorial Taguchi experiment has been used to identify the effect of key operating factors on output measures. Hwang et.al (2009) proposed multi-layer electrodes to coat TiC layer on Ni work piece surface. An L9 Taguchi experimental design method has been used for experiments. The coating obtained has excellent abrasion resistance at room temperature.

Al and Al alloys due to its light weight and high specific strength has recently attracted considerable attentions in automotive and aerospace industry as asubstitution material for steel, but have limited for thewear resistance.In order to improve their wear resistance, surface coatings can be a promising approach.Tungsten (W) and Tungsten carbide (WC) materials are used as a material for surface modification due to its high hardness, wear resistance and strength, ideal for tools, dies, machine parts,abrasives and resistance equipment.

In this work, electrode prepared with W and Cu powder by powder metallurgy route used as tool material and pure aluminum (Al) was used as work piece (WP).Using reverse polarity (tool as anode and work-piece as cathode) in electro discharge machine a composite layer of WC-Cu was deposited on the work-piece surface to produce a hard and wear resistance coating layer on Aluminum surface. The tool for EDC was prepared at various compaction pressures and at composition of 50:50 for W and Cu. The Deposition Rate and Tool Wear Rate at various parameters in EDM were analyzed. An L18 Taguchi experiment was considered to identify the effect of key parameters on output.

2 Experimentation

2.1 Tool Electrode Preparation

Electrodes used for EDC was made with mixtures of copper and tungsten at 50:50 wt%.The electrodes consist of two parts; a tool extension part for proper holding the tool electrode in EDM system which was made with mild steel and a PM compacted pellet which actually act as electrode and from which material is eroded and deposited on Al work piece. For making pellets copper and tungsten powderswere mixed together by using mortar and pestle made of ceramic. Powders were compacted at compaction pressures of 150 MPa and 200 MPa by using a compaction die of 12.5 mm diameter. The compacted pellet and tool extension part then brazed together. The PM compacted tool electrodes are shown in Figure 1.

Figure 1PM compacted tool electrodes

2.2 Experimental Planning

To optimize the parameters affectingthe electro discharge coating (EDC), Design of Experiments (DOE) based on Taguchi method was considered.DOE techniques helpful to find out the effects of individual parameter those affect the developed coating by EDC.As an alternative to traditional design methods, the Taguchi method wasused to study the various parameters those are affecting the performance with only a small number of experiments. The experiment design involves selecting appropriate orthogonal arrays to arrange the parameters affecting the process and their levels.

The signal-to-noise (S/N) ratio and the analysis of variance (ANOVA), was employed to find out the optimum levels and to analyze the effect of EDM parameters on Electro Discharge Coating (EDC) process.

For the purpose of observing the influence of the process parameters in EDC, the process parameters like peak current, pulse on time were varied during EDC and tool compaction pressure (TP) for tool preparation was also varied. The other parameters i.e. voltage =40 V, duty factor =50%, were kept constant for the experiment.The EDC process parameters and their levels considered for this experiment are shown in Table 1.

Table 1 EDC Process Parameters

Parameters	Level		
	1	2	3
Tool compaction pressure (MPa)	150	200	
Pulse current(A)	2	3	4
Pulse on time (μs)	100	200	300

2.3 Experimental Details

To deposit WC-Cu coating on Alumunium substrate, experiments were conducted with Electronica Electraplus PS 50 ZNC Die Sinking type electro discharge machine. Commercial grade EDM oil was used as dielectric without any flushing between the electrodes.The process parameters were varied as per the experimental planning described in table-2. The prepared tool electrode was kept as anode and Alumuniumwork-piece as cathode in electro discharge machine. In presence of dielectric,during discharge process tool electrode worn out and deposited over the work piece surface. Figure 2 shows the principle of EDC process, where a general purpose EDM machine is used and powder metallurgy tool compact istaken as tool electrode. During the process the tool electrode worn out and tungsten (W) reacted with decomposed carbon from the dielectric to form WC which again deposited along with copper that is coming out from tool electrode anddeveloped a WC-Cu coating layer on the Aluminumsubstrate. The coating developed on Al is shown in Figure 3.

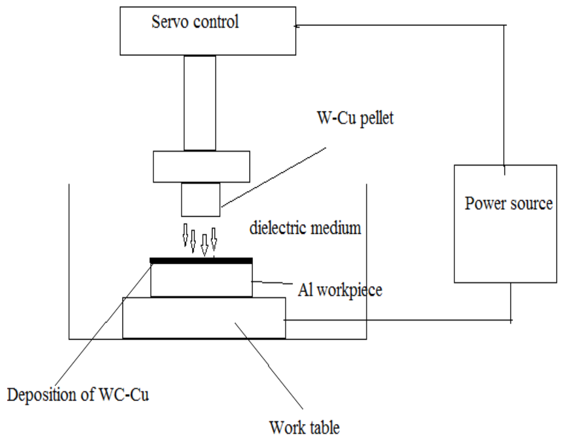

Figure 2 Schematic diagram of principle of EDC

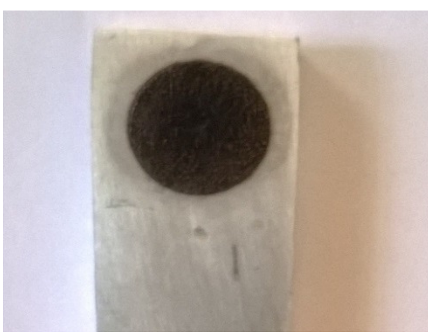

Figure 3 WC-Cu coating on Al work piece

The deposition rate of the composite layer was calculated by measuring the weight of substrate before and after the experiment. The difference in weight indicated the amount of material transferred from the tool to work-piece or substrate material. The deposition rate (DR) was calculated by considering the experimental time as per Eqn. 1.

$$\mathrm{DR} = \frac{\text{WP wt before expt} - \text{WP wt after expt}}{\text{Time of experiment}} \quad (1)$$

Similarly tool wear rate (TWR) was also measured by dividing the difference between the initial and final weight of the tool with experimental time as per Eqn. 2.

$$\mathrm{TWR} = \frac{\text{Tool wt before expt} - \text{Tool wt after expt}}{\text{Time of experiment}} \quad (2)$$

3 Results and Discussions

The details of deposition Rate and tool wear rate are given in Table 2 for different experimental condition. The experimental data was analyzed on the basic of S/N ratio and Analysis of variance (ANOVA).

Table 2 Experimental Results

Ex No	TP (MPa)	Ip (A)	Ton (μs)	DR (g/min)	TWR (g/min)
1	150	2	100	0.0072	0.0610
2	150	2	200	0.0067	0.0878
3	150	2	300	0.0056	0.0757
4	150	3	100	0.0156	0.1238
5	150	3	200	0.0161	0.1429
6	150	3	300	0.0142	0.1044
7	150	4	100	0.0137	0.0941
8	150	4	200	0.0204	0.1547
9	150	4	300	0.0155	0.1081
10	200	2	100	0.0091	0.0651
11	200	2	200	0.0116	0.0985
12	200	2	300	0.0105	0.0755
13	200	3	100	0.0094	0.0843
14	200	3	200	0.0158	0.1250
15	200	3	300	0.0111	0.0862
16	200	4	100	0.0114	0.1117
17	200	4	200	0.0144	0.1454
18	200	4	300	0.0111	0.1080

3.1 Analysis of S/N ratio

Taguchi stresses the study on influence of S/N ratio on quality characteristics. So that variation can be controlled on quality characteristics. The S/N ratio is defined as the ratio of mean to standard deviation. Here the S/N ratio was considered “larger is better” for deposition rate and “smaller is better” for tool wear rate. For “larger is better”S/N ratiowas calculated as per Eqn. 3

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum\frac{1}{y2}\right] \qquad [3]$$

Similarly for “smaller is better” the S/N ratiowas calculated as per Eqn. 4

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum y^2\right] \qquad [4]$$

Where n is the number of measurements in a row, in this case n=1 and y is the measured value in a row. After calculating the S/N ratio for each experiment, the average S/N valuewas calculated for each factor and level. The average value obtained graphically is known as S/N ratio curve. S/N ratio values for deposition rate by factor level are shown in Table 3.

From the table it is clear that the most significant factors that influencing deposition rate is peak current and then pulse on time. Tool compaction pressure has less influence on deposition rate as compared to other two factors. Effect of different parameters on deposition rate by main effect plot for S/N ratio is shown in figure 4.From the Figure 4 it has also been found that when compaction pressure increases from 150 MPa to 200 MPa the material deposition rate decreases. Therefore, a larger material deposition can be obtained for tool prepared at lower compaction pressure. This is because at higher compaction pressures the tool materials are firmly bonded and the bond between the powder particles is strong enough to reduce the material transfer rate from the powder compacted electrode to Al work piece.

Table 3 S/N ratio for deposition rate by factor level

Level	Tool Pressure	Ip	Ton
1	-38.62	-41.75	-39.41
2	-38.84	-37.44	-37.45
3		-37.01	-39.32
Delta	0.22	4.74	1.96
Rank	3	1	2

When peak current is increasing from 2A to 3A the deposition rate is also increasing. The same trend is followed when the peak current further increased from 3A to 4 A, even though the change of deposition rate is not that much increased as compared to the increase from 2A to 3A. The reason is that, during electro discharge process at high current more material is disintegrated from the powder compacted electrode and deposited on the substrate surface.At higher current due to strong spark there is a possibility to removal of some pre-deposited coating layer or substrate material, which causes an overall reduction in deposition rate.

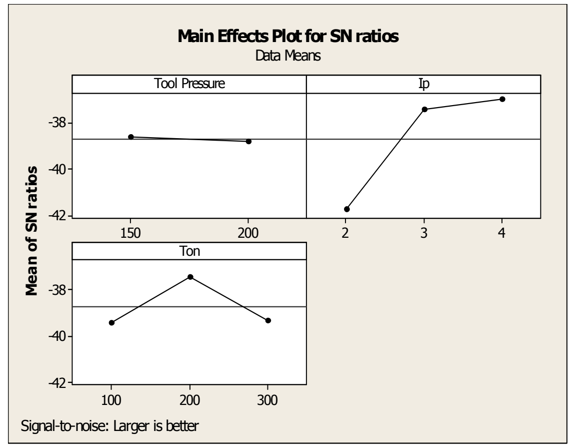

Figure 4 Effects of Process parameters on deposition rate

When pulse on time increases from 100 to 200µS the deposition rate is also increases. At higher pulse on time, it has a more dominant effect on input energy. Due to the higher temperature generated more powder material is eroded from the electrode. But it is found that when pulse on time is further increased to 300µs the deposition rate shows a decreasing trend. At higher pulse on time the coating obtained is more rough and brittle and hence most of the material deposited is not properly bonded to the Al work piece.

The optimum parameters for higher deposition rate are found for using a tool electrode prepared with 150MPa compaction pressure, 3A peak current and 200µs pulse on time.

Table 4 S/N ratios for tool wear rate by factor level

Level	Tool Pressure	Ip	Ton
1	19.84	22.36	21.20
2	20.25	19.25	18.20
3		18.53	20.74
Delta	0.41	3.83	3.01
Rank	3	1	2

S/N ratios for tool wear rate by factor level are shown in Table 4.

From the table it is found that, similar to the deposition rate,the primary factor influencing tool wear rate isapplied peak current during discharge process.

Pulse on time (Ton) also has a significant influence on tool wear rate. The least affecting factor is tool compaction pressure;

Effect of different parameters on tool wear rate by main effect plot for S/N ratio is shown in Figure 5. It is clear from the graph plotted for S/N ratios that, the tool wear rate is more for using electrode prepared at lower compaction pressure i.e. 150MPa and less for tool prepared at higher compaction pressure i.e. 200MPa. This is because of the lower binding energy of the powder particles at low compaction pressure which enhances the erosion of tool material for electrode prepared at lower compaction pressure.

The tool wear rate is increases as peak current increases during EDC process. The higher peak current has a dominant effect on input energy and hence more temperature is generated during sparking whichmelted and eroded tool electrode at faster rate and at the end tool wear rate increased.

The pulse on time has also a significant influence on tool wear rate and it is evident from the fact that tool wear is increased when pulse on time is increases from 100 to 200µS. Due to the strong spark generated during discharge at 200µS pulse on time;more tool wear rate is observed. But when pulse on time is further increased to 300µS the tool wear is rapidly decreased. The main reason for this, at high pulse on time more heat is generated and hence diameter of discharge has increased. But energy densityon the discharge spot will reduce and there will be an undesirable heat loss which will not contribute to material removal from tool and hence tool wear rate will reduce (Alidoosti et.al (2013)). The optimum parameter combination for lowest tool wear rate is tool electrode compaction pressure 150MPa, applied peak current 4A and pulse on time of 200µs during EDC.

The ANOVA table is for 95 % confidence level. The P-value reports the significance level (suitable and unsuitable) for deposition rate and tool wear rate in Table5 and Table 6 respectively.

The percent numbers indicates that the tool pressure, peak current, pulse on time has significant effects on the deposition rate. It can observe from the table the tool pressure, peak current, and pulse on time affecting the deposition rate by 0.142 %, 55.01 % and 9.81 %.And p values of less than 0.005 for peak current means it is a significant factor on deposition rate.

From the ANOVA for S/N ratios in case of tool wear rate the percent numbers indicate that they have significant influence on response. It can observed that the tool pressure, peak currentand pulse on time affecting the tool wear rate by 0.807 %, 53.21 % and 33.69 % respectively. Here for both peak current and pulse on time the p values are less than 0.005, which indicates that they are the most significant factors.

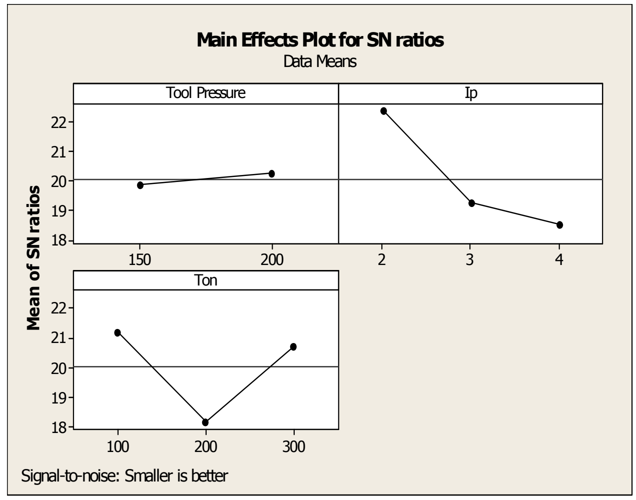

Figure 5 Effects of Process parameters on tool wear rate

5Conclusions

WC-Cu composite layer has been deposited successfully over Al work-piece surface by Electro Discharge Coating process.From the experimental results, it is found that, at high tool compaction pressure,bonding between powder particles is strong enough to reduce material transfer rate from tool electrode to work-piece material. Hence tool wear rate and deposition rate is reduces with increase in tool compaction pressure. Again, with increase of peak current (Ip),both deposition rate and tool wear rate increases due tofaster rate of disintegration and depositionof powdersfrom compacted tool electrode to the substrate surface. It is further observed that, when pulse on time (Ton) increases from 100 to 200µS, both depositions rate and tool wear rate increases, that is mainly due togeneration of high temperature and corresponding erosion of powder material from the tool electrode. However, when Ton increases from 200µSto 300µS deposition rate and tool wear rate decreases. At 300 µS, diameter of pulse increases but energy density on the discharge spot reduces and due to someheat loss which is not contributing to material removal from tool electrode, the tool wear rate and deposition rate reduces.

Table 6 ANOVA results for deposition rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage
Tool Pressure	1	0.214	0.2140	0.2140	0.05	0.829	0.142
Ip	2	82.391	82.3908	41.1954	9.42	0.003	55.01
Ton	2	14.695	14.6952	7.3476	1.68	0.227	9.81
Residual error	12	52.457	52.4575	4.3715			35.02
Total	17	149.757					

Table 7 ANOVA results for tool wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage
Tool Pressure	1	0.7526	0.7526	0.7526	0.79	0.392	0.807
Ip	2	49.6242	49.6242	24.8121	26.00	0.000	53.21
Ton	2	31.4226	31.4226	15.7113	16.46	0.000	33.69
Residual Error	12	11.4512	11.4512	0.9543			12.28
Total	17	93.2506					

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